Completed

NITROGEN FERTILIZER MANAGEMENT TO REDUCE GROUNDWATER DEGRADATION

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OBJECTIVES:

1. Assess the sensitivity of leaf nitrogen (N) concentration to overfertilization.

2. Determine the relationship between leaf N concentration and tree productivity. (i.e., reassess the validity of the currently-accepted leaf N diagnostic guidelines)

3. Assess the relationship between the rate of applied fertilizer N, tree N status and the percentage recovery of isotopically labeled (^{15}N-depleted) fertilizer N.

4. Assess nitrate leaching below the root zone and its relationship to fertilizer N application rate and tree N status.

5. Refine current management guidelines for N usage which will help maintain productivity while reducing the amount of fertilizer N leached below the root zone under conditions typical of the Northern San Joaquin Valley.

DESCRIPTION:

Two research plots were established in nitrate-sensitive areas of Stanislaus County - one in Salida and one in Ceres. Both orchards, planted in 1980, are growing in Hanford sandy loam soils.

The project was conducted in 3 phases. In 1990, pretreatment baseline data were obtained (on tree yields, leaf N, concentrations, and soil and irrigation water nitrate concentrations); and experimental plots were established. From 1990-1993, differences in tree N status and related effects were established (including yield differentials and soil nitrate levels) using 4 levels of applied fertilizer N (0, 125, 250, and 500 lbs N/acre/year) fertilizer was applied as a 1/3, 2/3 split in April and early October, respectively which is typical of grower practice in that area. From 1993-1995, a uniform amount of isotopically labeled ammonium sulfate was applied to selected trees differing in tree N status, and tree recovery of labeled fertilizer N and the likelihood of nitrate leaching below the rootzone was determined.

RESULTS

Current fertilization practices in many almond orchards favor overfertilization - the application of fertilizer nitrogen in excess of the tree's capacity to utilize it. The following evidence is consistent with that interpretation:

The presence of high residual levels of nitrate in the soil (data not presented). These may result from the use of high nitrate - containing irrigation water (33 ppm nitrate in Salida and 44 ppm nitrate in Ceres) as well as excessive application rates of fertilizer N.

Lack of a yield response to the fertilizer. A significant yield reduction in unfertilized trees occurred only in 1993, which was 3 1/2 years after the last fertilization (Table 1). The lack of significant yield reduction in unfertilized trees in 3 out of 4 years (Table 1) indicates that fertilization was not required annually to maintain productivity under the given orchards conditions. We must conclude that sufficient N is available from other sources (e.g. high nitrate irrigation water, etc.) to maintain productivity without supplemental fertilization.

High leaf N concentrations. Pretreatment (1990) leaf N concentrations averaged above 2.6% in both orchards (Table 2). There is no evidence that almond yields increase above a leaf N concentration of 2.5%. Leaf N concentration appears to be insensitive to overfertilization, thus there is virtually no difference in leaf N concentrations between trees receiving 250 lbs N/acre/year and those receiving 500 lbs N/Acre/Year (Table 2). This probably means that at higher levels of available soil N, tree capacity for N uptake is limited and additional fertilizer N accumulates in the soil and becomes vulnerable to loss - probably leaching- in coarse-textured, sandy soils. On the basis of our data, the ideal range of leaf N concentration to both maintain yield and minimize subsequent leaching appears to be between 2.3% and 2.5%N.

Preliminary analyses indicate not only that almond tree productivity is N-limited when mid-summer leaf N concentration is below 2.2%, but yield may even be reduced when leaf N concentrations are between 2.2 and 2.3%. A major determinant of yield is fruit number. As flower differentiation occurs in the summer soon after diagnostic leaf sampling in July, our data suggest that leaf analysis is more predictive of the subsequent year's crop than the current year's crop. Thus, a leaf N concentration below 2.3% in July 1993 may be predictive of a reduced crop in 1994.

Tree N status and recovery of isotopically labeled fertilizer N. Following three years (1990-1993) of differential rates of N fertilization, we selected 18 trees (Salida orchard) varying in leaf N concentration (Table 3), and 1993 yield relative to pretreatment yields in 1990. Labelled ammonium sulfate was applied post-harvest (October 2, 1993) at the rate of 166 lbs N/Acre/Year. Trees also received 84 lbs N/Acre/Year (non-labeled) in April 1994. We then determined total recovery of labeled N in the fruit (1994). Four of the trees were also excavated completely in February, 1995 and analyzed for residual labeled N content.

Between 65% and 79% of the labeled N absorbed by the trees was in the fruit with the remainder present in the perennial tree parts (branches, trunk, roots, etc., Table 3).

Trees that were fertilized at the rate of 500 lbs N/Acre/Year only recovered about 20.5% of the fertilizer N applied (Table 3). In contrast, trees that received 0, 125 or 250 lbs N/Acre recovered 30% of the labeled N applied - about 50% more. Thus, the high rates of N fertilizer application between 1990 and 1993 reduced recovery of fertilizer N in 1993-1994. Two factors may have limited uptake of fertilizer N by trees receiving 500 lbs N/A/Year between 1990 and 1993: a) dilution of labeled fertilizer N in the soil by high residual levels of nitrate (Table 3) and b) reduced tree N demand. As discussed below leaching did not occur during the Winter of 1993-1994.

We are finding (in other studies) that the N requirements of fruit growth, shoot growth and nut fill are important determinants of N uptake. During the post-harvest and dormant periods, growth nearly ceases, and dormant trees have a greatly limited capacity for N uptake. In years of heavy rainfall, significant leaching can occur between November and March. High residual levels of nitrate in the soil after harvest may be vulnerable to leaching within one to two months. Thus, a) low N uptake by trees during the post-harvest and dormant periods coupled with b) vulnerability of nitrate to leaching with the winter rains should discourage heavy post-harvest applications of fertilizer N. The Winter of 1993-1994 was relatively dry, receiving only about 2/3 of the normal annual rainfall. Fertilizer recovery (Table 3) may have been even lower if we had conducted the study in 1994-1995 when rainfall was nearly double the long-term average. Our data do not allow us to determine how much of the labeled N recovery occurred between October, 1993 and March 1994 (bloom) and how much between bloom and harvest (August, 1994).

Relationship of nitrate leaching to fertilizer N application rate. Ponds were created at 6 different locations in the orchard during tree dormancy (when trees were leafless) to calculate soil hydraulic conductivity. Six additional sites throughout the orchard were equipped with tensiometers, soil solution samplers (at depths of 2, 3, 4, 5 and 6 feet), and neutron probe access tubes. Data were collected between June, 1993 and June, 1994. Our ultimate goal was quantify N fluxes below the root zone as a function of N fertilization rate. Achievement of that objective was complicated by sources of orchard variability which included (but were not limited to) a hardpan in much of the orchard between three and five feet. Conditions required to calculate soil hydraulic conductivity are violated by a hardpan which precludes one-dimensional (i.e. vertical) water flow.

Realistic comparisons of soil nitrate flux as a function of fertilizer N application rate were also confounded by soil spatial variability and the lack of irrigation water distribution uniformity. The overall mean irrigation water application rate averaged 0.10 in/hr, however, the rate varied 4 fold (from 0.05 to 0.20 in/hr) among the 6 monitoring sites in the orchard. Based on the application rates measured and the hours of application, mean total applied water was 40.6 inches from June 3, 1993 to June 2, 1994 but varied form 20.3 to 81.1 inches at our six monitoring stations.

Data from only one of the six monitoring sites in the orchard will be discussed because that site was not underlain by a hardpan and, therefore, reflects undisturbed water flow. A summary of the principal findings are presented below.

1. Cumulative water flux between June 1993 and June 1994 declined with depth i.e., 397 mm water passed the 2 foot depth, 133 mm passed the 3 foot depth, 42 mm passed the 4 foot depth and 7 and 8 mm of water passed the 5 and 6 foot depths, respectively.

2. The temporal patterns of water flux and nitrate flux appeared quite similar. This was anticipated because nitrate in the soil solution is known to move freely with the advancing water front.

3. In this specific orchard site and in this particular year of record, water and nitrate flux were consistently greater at the 3 foot vs. the 5 foot depth. The bulk of the almond root system is restricted to the top 3 feet of soil in this orchard and nitrate movement beyond that depth may become inaccessible to the tree.

4. Nitrate flux was considerably greater during the irrigation season than during the winter (Nov.-Feb.). This pattern must be considered within the context of the below-average winter rainfall (8.9 inches) during the season of record. Thus, nitrate flux below the root zone in winter is likely to be greater during years of more typical rainfall.

   (The rainfall during the winter of 1994-1995 exceeded the long term average rainfall by >50%.) We question the rationale of typical grower practice in that area. Currently, two-thirds of the annual N application is applied post-harvest in late September - early October. The accumulation of high amounts of nitrate in the soil at a time when a) tree demand for N is low and b) tree capacity for N uptake is decreasing places that nitrate in position to be leached beyond the root zone if significant winter rainfall occurs.

   Although we were not able to make definitive comparisons of nitrate flux among the four fertilizer N application rates, we can reasonably anticipate a heightened potential for leaching at the highest N application rate (500 lbs N/acre/year), if we consider the higher levels of nitrate in the soil (Table 3) and assume that water flux remains constant across treatments.

Table 1. Differential N Fertilization and Almond Yields in 2 Stanislaus County Orchards

Orchard	Treatment[z]	Meat Pounds Per Acrez[x]				
	(lbs N/A/Yr)	1990[y]	1991	1992	1993	1994
Salida	0	3508	3587 a	1470 a	1938 c	*
	125	3508	3554 a	1538 a	2735 ab	*
	250	3508	3421 a	1606 a	3120 ab	*
	500	3508	3610 a	1789 a	3710 a	*
Ceres	0	4444	1633 a	2512 a	2421 b	3967 a
	125	4444	2309 a	2542 a	2956 ab	3837 a
	250	4444	1807 a	2712 a	2913 ab	3786 a
	500	4444	1919 a	2879 a	3315 a	4008 a

[z] Treatments initiated post-harvest in 1990

[y] Pretreatment yields

[x] Values sharing a common letter within columns (years) in a given orchard do not vary statistically

* Plot treated with labeled N to assess effect of tree N status on fertilizer N recovery

Table 2. Changes in Leaf N Concentration With Rates of Applied Fertilizer N in 2 Stanislaus County Orchards

Orchard	Treatment[z]	Leaf N Concentration (% dry wt.)[x]				
	(lbs N/A/Yr)	1990[y]	1991	1992	1993	1994
Salida	0	2.61	2.27c	2.13c	2.28c	*
	125	2.61	2.34bc	2.18c	2.40bc	*
	250	2.61	2.36bc	2.24b	2.52b	*
	500	2.61	2.42ab	2.37a	2.68a	*
Ceres	0	2.69	2.49a	2.29b	2.37c	2.51a
	125	2.69	2.48a	2.30b	2.51b	2.64ab
	250	2.69	2.49a	2.44a	2.68a	2.75bc
	500	2.69	2.53a	2.49a	2.74a	2.82c

[z]Treatments initiated post-harvest in 1990.

[y]Pretreatment values.

[x]Values sharing the same letter within a column (same orchard) did not differ statistically at $P<0.05$.

*Plot fertilized with labeled N to asses effect of tree N status on fertilizer N recovery.

Table 3. Effect of previous fertilizer application rate on recovery of a uniform post-harvest application of isotopically-labelled ammonium sulfate[z]

Tree	Fertilization (1990-1993) (lbs N/A/Yr)	1993 Leaf N (% dry wt.)	Soil Nitrate-N[y] (ppm)	Labeled N recovery (%)		
				Fruit Aug 1994	Tree Feb 1995	Total
10-19	0	2.06	1.95	24	--	--
14-19	125	2.28	0.81	26	7	33
18-12	0	2.37	0.81	19	8	27
10-8	125	2.46	0.37	22	--	--
10-9	125	2.65	--	22	--	--
6-10	250	2.59	15.5	27	--	--
10-11	500	2.70	193.6	14	7	21
10-13	500	2.92	48.1	15	5	20

[z] 872 g labeled N per tree was applied on 2 October, 1993

[y] mg N-NO_3^- per g of oven-dried soil. Analyses based on 4 soil cores per tree between 2 and 2.5 feet deep 10 days prior to application of labeled N.